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The effects of dimmable road lighting: A comparison of measured and perceived visibility

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ABSTRACT

By dimming road lighting, energy can be conserved without compromising traffic safety. This paper presents a study carried out on the effect of different lighting levels from road luminaires on drivers' visual performance on a low traffic urban road. The small uniform target was used to evaluate the visibility performance of the drivers. The results obtained from subjective graded visibility were compared with contrast and the Adrian model. Results indicated a strong correlation between subjective graded visibility and contrast ($R^2 = 0.94$) and a positive correlation between subjective graded visibility and the Adrian model ($R^2 = 0.88$). Target's location in relation to road luminaires had a considerable effect on its visibility. However, visibility is not a monotonic function of road lighting level. In the absence of glare from an oncoming car, 49% (3557 lm) of road lighting intensity provided better contrast and mean visibility than 100% (7252 lm) and 71% (5179 lm) of road lighting intensities. The glare from oncoming cars reduced visibility. However, no statistically significant effect of road lighting level on visibility under glare could be found.

1. Introduction

Detecting targets on a road is directly dependent on visibility, which in turn is related to traffic safety (Bremond, Bodard, Dumont, & Nouailles-Mayeur, 2013). Road lighting improves drivers' visual performance at night, leading to a reduction in the number of accidents (Raynham, 2004). Wanvik (2009) estimated the effect of road lighting on accidents on Dutch roads during 1987–2006 as −49% on fatal crashes and −46% on injury crashes. In another study, Elvik (1995) reviewed 37 studies from 1948 to 1989 in different countries and discovered that road lighting is responsible for a 65% reduction in night-time fatal accidents, a 30% reduction in night-time injury accidents, and a 15% reduction in night-time property-damage-only accidents. A brief overview of 62 before and after studies in 15 countries indicated that road lighting during the night reduced the number of accidents on average by 30% (CIE, 1993).

However, the positive effect of road lighting on traffic safety comes at a cost. IEA (2006) has estimated that in 2005, lighting consumed 19% of the world's electricity, outdoor lighting amounting to about 8% of total lighting electricity consumption.

The demand for road lighting during the night depends on several factors. For example, a snow-covered road requires less light than a dry road to fulfil the standard luminance requirements (luminance refers to luminous intensity per unit projected area). According to Wanvik (2009), the luminance level of a snow-covered road surface increases by a factor of 4 or 5 compared to a dry road.

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Static road lighting provides a standard amount of light in all circumstances, e.g. traffic and weather conditions, while unnecessary light can be avoided when and where possible by using dimmable road lighting. Traffic safety, energy consumption and minimization of light pollution are important factors in developing new intelligent lighting designs. In Norway, for example, dimming the luminaires due to traffic, climate conditions, etc., resulted in 30% energy saving and prolonging the life expectancy of the lamps (BSREC, 2007). Hogema and Kaptein (1998) conducted a field study on the effect of dimmable road lighting on traffic behaviour and road safety. They collected data in three measurement periods: a no road lighting period, a normal road lighting (100%) period, and a dimming period (20%, 100% or 200%). The results concluded that in dry weather and low traffic volume condition, a lower lighting level (20% or 0.2 cd/m^2) can be applied without having any negative road safety consequences.

The headlights of oncoming cars cause glare, which in turn reduces visibility. Glare refers to the loss of retinal image contrast as a result of intraocular light scatter, or stray light (Aslam, Haider, & Murray, 2007). This causes extra light to fall on the image of the object and will lead to veiling luminance. There are four types of glare: (1) Saturation glare refers to exposure of a large part of the visual field to a long period of brightness, such as on sunny days; (2) Adaptation glare refers to a sudden and large increase in luminance of the whole visual field; (3) Disability glare refers to the scattering of light in the eye that disables the visual system to some extent; (4) Discomfort glare refers to discomfort caused by glare without necessarily impairing vision (Boyce, 2008). Many factors contribute to the effects of glare. The sensation depends on the luminance of the glare source (e.g. an oncoming car's headlights), reflection of the road surface (e.g. from snow or ice) as well as background luminance, which all have an effect on the adaptation level of the driver, not to mention other variables on the driver's part such as age and fatigue level. Disability glare that is caused by the headlights of an oncoming car on drivers' vision at night is examined in an experiment conducted in this study.

The effects of different lighting intensities must be studied in different scenarios on the visibility of drivers in order to determine the best level of road lighting intensity for best visibility and safer traffic conditions. Not much research is available about the combined effect of road lighting (dimmable) and car headlights. Moreover, most research has been devoted to static road lighting (no dimming), not on intelligent road lighting. Bacelar (2004) calculated the visibility level (VL) of standard targets with a reflection of 0.2 at different distances from the vehicle (a constant distance of 40 m from the vehicle for low-beam headlights and 90 m for high-beam headlights) along the axis of the road using the Adrian model (Adrian, 1989). His results indicated a variation in visibility level in (1) car headlights only, (2) road lighting only, and (3) the joint effect of headlights and road lighting conditions. VL with only headlights was constant at constant distances from the car. VL was lower at far distances using high-beam headlights than near distances using only low-beam headlights because of the lower illuminance on the target and its smaller angular size at the greater distance. VL with only road lighting was different at different locations due to light distribution. Finally, he noted that using road lighting and low-beam car headlights separately results in better visibility than when they are being used together. Ekrias, Eloholma, and Halonen (2008) studied the combined effect of car headlights and road lighting. The results indicate that the joint use of car headlights and road lighting does not improve the luminance contrast of the targets on the road. The impacts were dependent on the type of car headlights, the reflection and position of the target, the position of the car, and the road lights. The only research that considered the effect of dimming on the visibility of drivers was by Bacelar (2005). However, the research did not consider the effect of car headlights. The experiments were executed with the observer's visibility assessment of the targets on different road lighting illuminations. The results indicated that there was a good nonlinear correlation between the decrease of luminous flux and VL. Overall, the dimming of road lights up to 50% had negligibly reduced the observer's visibility performance. He also noted that the efficiency of the road lighting installation and the photometric characteristics of the lamp have an important effect on visibility. Installation had good longitudinal uniformity (0.7) and overall luminance uniformity (0.6). (Longitudinal uniformity refers to the ratio of the minimum to the maximum luminance along a line parallel to the length of the roadway. Overall luminance uniformity refers to the ratio of the minimum luminance at a point to the average road surface luminance over an evaluation area.) Another outcome of his study was that the position of the target had a more significant effect than dimming the lights.

The goal of this study was to find the combined effect of different lighting levels and car headlights on small uniform target visibility. The effect of glare from an oncoming car on a driver's visual performance was also estimated. This first phase of the study considers High-Pressure Sodium (HPS) lamps. The next phase, to be reported in a separate paper, considers LED lamps.

2. Visibility performance assessment

Drivers' visibility performance can be assessed in three different ways: contrast, visibility level model, and perceived visibility grade on a subjective scale.

2.1. Contrast

The visibility of targets on the road depends mainly on contrast (Ekrias et al., 2008). The higher the contrast, the more visible the target becomes. The contrast of targets can be measured by both Weber's and Michelson's contrast, in which Michelson's contrast is used to measure contrast in a periodic pattern (e.g. sinusoidal grating) and Weber's contrast is used